AD-A157 026 BTREE: A FORTRAN CODE FOR B+ TREE(U) NAVAL SURFACE 1/1
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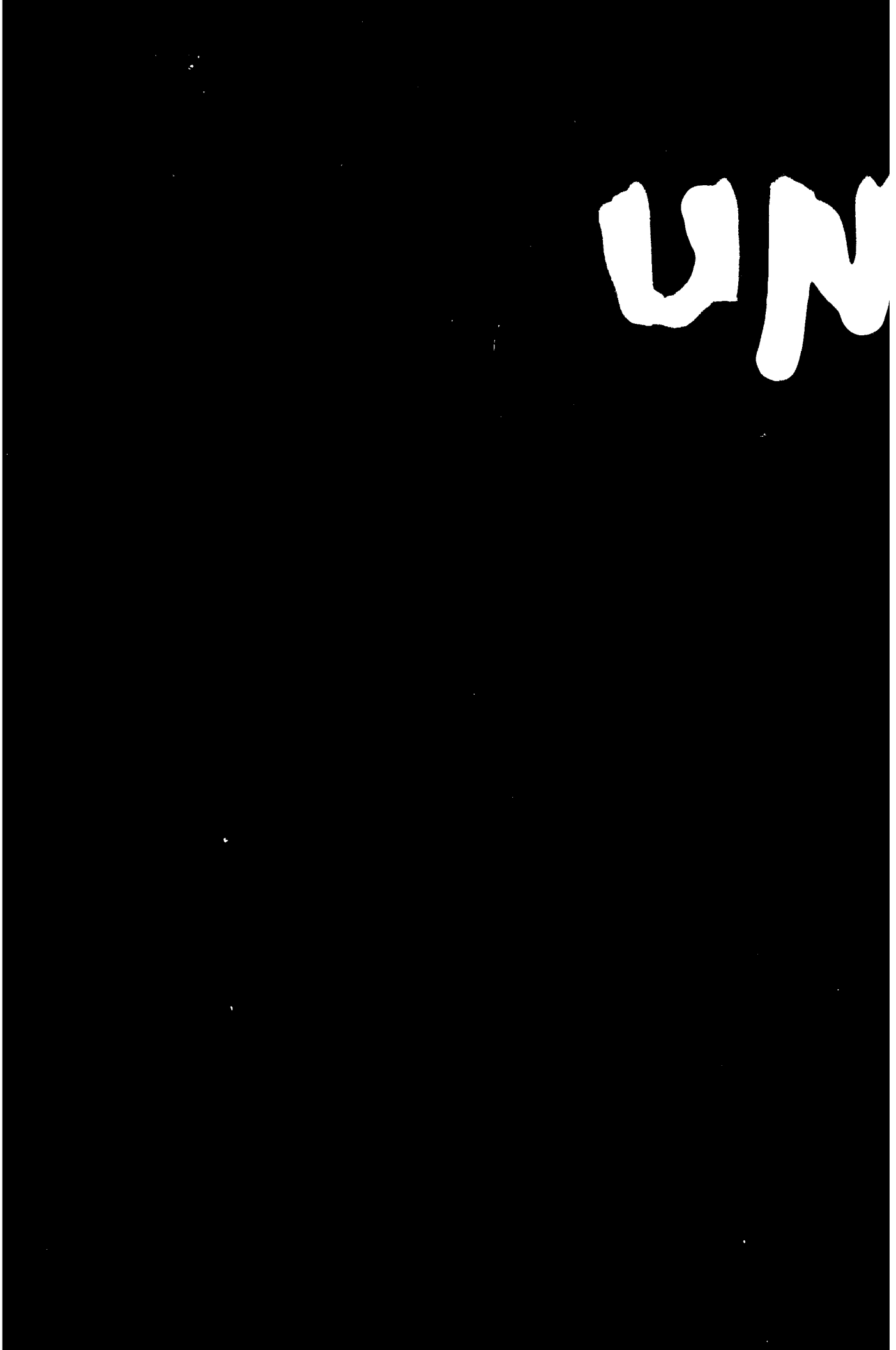

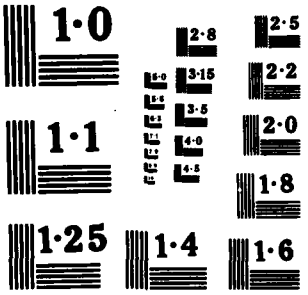

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This report discusses and documents a FORTRAN code for a B+ Tree, a data structure which if frequently used is the foundation of a database manager.

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FOREWORD

This report contains documentation for a FORTRAN implementation of a B+ tree, a data structure which is often used as the foundation of a database manager. Because the code is written in a high-level language, it is basically transportable to any computer with FORTRAN capability (minor modification may be required for compatability with a host computer's operating system and compiler). The work was done as a first step towards developing a user-friendly, interactive database manager needed by U31 to support studies requiring the extensive use of minefield planning codes.

This work has been supported by the Mine Improvement Program at NSWC under Project S0267.

Approved by:

Ira M Blatstein

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Radiation Division

Additional keywords: Interactive documentation; Implementation; C

CONTENTS

ILLUSTRATION

INTRODUCTION

A B+ tree is a data structure which is particularly well suited for storing the keys which identify the records in a database. The objective of a B+ tree, hereafter referred to simply as a tree, is to minimize the number of mass storage accesses required to find a specified key. A conceptual representation of a tree, containing the letters {B,D,E,G,H,L,N,R,S} as keys, is shown in Figure 1.

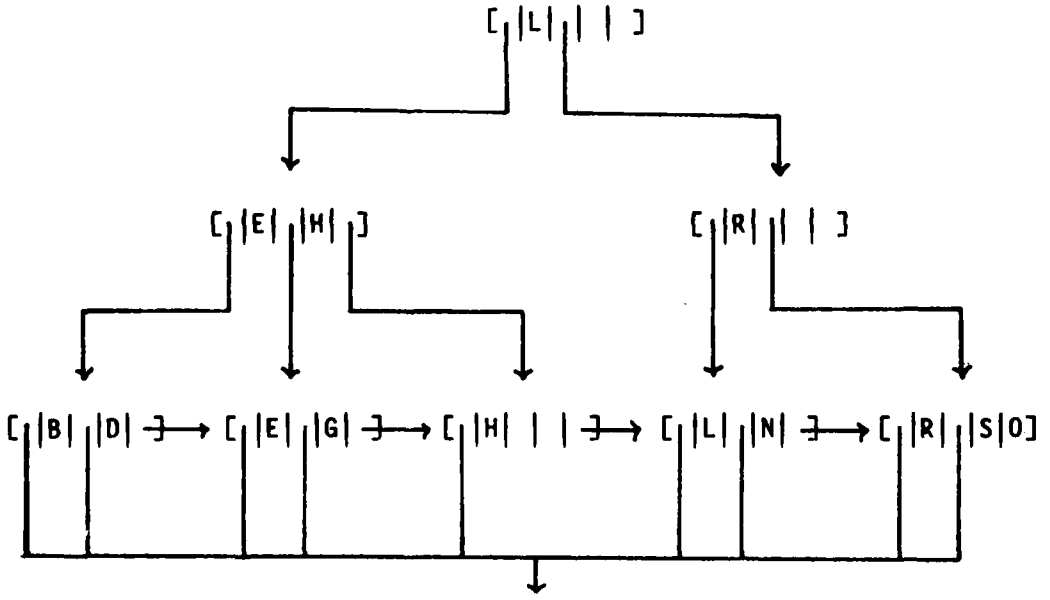

FIGURE 1. EXAMPLE OF A B+ TREE

A tree corresponds to a file, each node of the tree corresponds to a record in that file, and a pointer between nodes corresponds to the record number of the node to which it points. The tree in Figure 1 has a nodal capacity equal to 2. The nodes on the bottom level, called the leaves of the tree, contain all the keys. Each leaf points to its neighbor on the right, and the rightmost leaf points to zero, indicating that it is the last leaf in the tree.

All key searches begin at the top node, known as the root. To find the letter G, for example, the left node on the second level is searched after the root because G precedes L in alphabetical order. Since G is between E and H, the second leaf from the left is searched next, and the key is found. Thus, the number of accesses required to find a key is equal to one more than the height of the tree. As keys are added to the tree, leaves become full and split in half; as keys are removed, adjacent leaves may merge. A complete description of splitting and merging rules will not be given here, but the interested reader is referred to the excellent introduction presented by Comer[1]; a more analytical discussion can be found in Knuth[2].

Documentation for a database manager based on the code listed in Appendix B is contained in Winston[3].

SPECIFICATIONS

The implementation listed in Appendix B is written in a version of FORTRAN 77 for a DEC VAX/780 computer with the VMS operating system. In particular, files names are at most 9 characters long, and have extenders with as many as 3 characters. A tree called (name) can have as many as 3 files associated with it: (name).KEY, (name).NOD, and (name).REC. The file (name).KEY corresponds to the tree itself, and (name).NOD and (name).REC are node and record stacks, respectively. The numbers of the nodes and data records that are deleted from the tree as a result of key deletions are saved by the stacks and reused as needed. Stack files containing no numbers are automatically erased from the system.

Records corresponding to nodes have a length of 256 bytes, and the maximum tree height is equal to 5. Keys have a maximum length of 20 characters, and the tree can accomodate up to 65,535 keys. Application programs which call BTREE can have up to 10 trees open simultaneously, via the logical device unit numbers 1,2,...,10.

USAGE

A call to BTREE is accomplished by the standard FORTRAN syntax

```
CALL BTREE (LTR,LDU,A,MAXLEN,IREC,IERR).
```

A description of the input and output parameters follows:

INPUT:

LTR (CHARACTER*1)		COMMAND
A	----------	(A)dd a key to the tree
C	----------	(C)reate a new tree
D	----------	(D)elete a key from the tree
F	----------	(F)irst key in the tree
G	----------	(G)et first occurrence of a partial key
O	----------	(O)pen an old tree
S	----------	(S)uccessor key

LDU (BYTE)	unit number under which the tree communicates with mass storage; permissible values are 1,2,...,10
A (CHARACTER*20)	full key (required for LTR = 'A','D') partial key (required for LTR = 'G') tree name (required for LTR = 'C','O')

MAXLEN (INTEGER*4) maximum key length; cannot exceed 20 (required for LTR = 'C')

OUTPUT:

A (CHARACTER*20) value of the last key accessed

IREC (INTEGER*4) number of the data record associated with the last key accessed

IERR (BYTE) ERROR CODE

0	----------	successful execution of the command
1	----------	illegal value of the parameter 'LTR'
2	----------	attempt to create an existent tree
3	----------	attempt to access a nonexistent tree
4	----------	attempt to find a nonexistent key
5	----------	no successor key exists
6	----------	attempt to insert a key currently in tree

The "get" command is of particular interest because it searches the tree for the first occurrence of a left-justified string within a key. This feature is useful when it is desired to access a particular class of keys, all of which begin with the same string of characters. Setting A equal to the string and executing a "get" command finds the first key which has A as its prefix; successive "successor" commands find the remaining keys in the class. The full key value returned by A should always be checked for its prefix after each such call. This procedure is especially fast because the "successor" command usually does not require a mass storage access. Unlike the "get" command, the "delete" command fails to execute unless the full key value is specified.

Either an "open" command or a "create" command must be executed prior to performing any other operations on a particular tree.

BTREE creates trees which contain unique keys only; an attempt to insert a duplicate key will not execute (IERR = 6). Also, the code prevents the creation of a new tree having the same name as a tree currently on the system (IERR = 2).

RECONFIGURATION

It may be desirable to alter some of the specification parameters to make BTREE mesh more efficiently with a particular application program. These adjustments are indicated as follows:

(a) To change the maximum key length to k characters, declare the passing parameter A and the internal variable KEYVAL as CHARACTER*k;

(b) To change the height of the tree to h, declare the arrays BUF(0:h) and PATH(0:h);

(c) To change the number of trees open simultaneously to t, declare the arrays HTREC(t), MAXREC(t), HTNOD(t), MAXNOD(t), ROOT(t), MKL(t), HEIGHT(t), NAME(t), MARKS(t), MANYS(t), and BLOCS(t);

(d) To change the size of the nodes to s bytes, change all CHARACTER*256 declarations to CHARACTER*s, assign FULL = (s-4)/ONE in SUBROUTINE BTREE, and assign RECL = s in the OPEN statement in SUBROUTINE NEWTREE.

While it is possible to increase the maximum number of keys allowed in the tree, the alterations required by the code are far more intricate and complex. Changing to a 3-BYTE symbol code for integers would allow up to 16,777,215 keys, but would entail, among other things, rewriting the functions VAL and SYM and checking all sections of the code dealing with loading information into the nodes because 3 bytes must be reserved for each integer instead of 2 bytes. In short, increasing the number of keys is not recommended. Moreover, specially tailored database programs are usually developed, or purchased, to maintain such large databases.

REFERENCES

1. Comer, D., "The Ubiquitous B Tree," Computing Surveys, Vol. 11, 1979, pp. 121-137.

2. Knuth, D., The Art of Computer Programming, Vol. 3: Sorting and Searching (Reading: Addison-Wesley, 1973), pp. 473-480.

3. Winston, E., BOSS: A FORTRAN Code for a Relational Database Manager, NSWC TR 85-56, June 1985.

APPENDIX A

SUBROUTINE DOCUMENTATION

SUBROUTINE BTREE

PURPOSE: To control the logic needed to execute the command requested by the value of LTR.

INPUTS:

LTR (= ABC)	CHARACTER*1	command letter
LDU (= IO)	BYTE	input/output device number
A (= NAME)	CHARACTER*20	key name if LTR = 'A','D',or 'G'
A (= KEYVAL)	CHARACTER*20	tree name if LTR = 'C' or 'O'
MAXLEN (= MKL)	INTEGER*4	maximum key length

OUTPUTS:

IREC (= PTR)	INTEGER*4	number of the data record associated with the last key examined
IERR (= ERR)	BYTE	error code number
A	CHARACTER*20	full value of last key examined
ONE	INTEGER*4	parameter equal to MAXLEN + 2
FULL	INTEGER*4	maximum number of keys in a node

EXTERNALS:

ADDKEY,NEWTREE,DELKEY,FIRST,GETKEY,OLDTREE,SUCCESSOR

SUBROUTINE MERGE

PURPOSE: To merge two adjacent nodes into a single node.

INPUTS:

LEAF	LOGICAL	.TRUE. if and only if the current node is a leaf
LFM	INTEGER*4	number of keys in the left node
RTM	INTEGER*4	number of keys in the right node
LFBLOC	CHARACTER*256	left node
RTBLOC	CHARACTER*256	right node
MKL	INTEGER*4	maximum key length
KEYVAL	CHARACTER*20	value of the last key examined
RTNOD	INTEGER*4	number of the right node
IO	BYTE	input/output device number
NAME	CHARACTER*9	name of the current tree
HTNOD	INTEGER*4	height of the node stack
MAXNOD	INTEGER*4	largest number yet assigned to a node
ONE	INTEGER*4	parameter equal to MKL + 2

OUTPUTS:

none

EXTERNALS:

STACK

SUBROUTINE ADJACENT

PURPOSE: To find a node adjacent to the current node.

INPUTS:

BUF	CHARACTER*256	array which contains the nodes in the current path
LEVEL	BYTE	level of the current node in the tree
NOD	INTEGER*4	number of the current node
BLOC	CHARACTER*256	current node
MANY	INTEGER*4	number of keys in the current node
ONE	INTEGER*4	parameter equal to MKL + 2

OUTPUTS:

RTNOD	INTEGER*4	number of the node to the right of the current node, if it exists; otherwise, the number of the current node
RTBLOC	CHARACTER*256	right node
RTM	INTEGER*4	number of keys in the right node
LFNOD	INTEGER*4	number of the current node, if no right node exists; otherwise, the number of the node to the left of the current node
LFBLOC	CHARACTER*245	left node
LFM	INTEGER*4	number of keys in the left node
KEYVAL	CHARACTER*20	value of the separator key

EXTERNALS:

VAL

SUBROUTINE DELKEY

PURPOSE: To delete a key and update the tree.

INPUTS:

IO	BYTE	input/output device number
NAME	CHARACTER*9	name of the current tree
HTREC	INTEGER*4	height of the record stack
MAXREC	INTEGER*4	largest number yet assigned to a data record
FULL	INTEGER*4	maximum number of keys in a node
HEIGHT	BYTE	height of the current tree
ONE	INTEGER*4	parameter equal to MKL + 2

OUTPUTS:

ROOT	INTEGER*4	node number of the root of the updated tree
HEIGHT	BYTE	height of the updated tree
HTREC	INTEGER*4	height of the updated record stack
MAXREC	INTEGER*4	largest number yet assigned to a data record
HTNOD	INTEGER*4	height of the updated node stack
MAXNOD	INTEGER*4	largest number yet assigned to a node

EXTERNALS:

GETKEY,STACK,ADJACENT,MERGE,PARENT,SHARE

SUBROUTINE SUCCESSOR

PURPOSE: To search for the key following the last key accessed.

INPUTS:

MARK	INTEGER*4	position in the current node of the last key examined
MANY	INTEGER*4	number of keys in the current node
ONE	INTEGER*4	parameter equal to MKL + 2
BLOC	CHARACTER*256	current node

OUTPUTS:

MARK	INTEGER*4	position of the next key in the node containing it
MANY	INTEGER*4	number of keys in the node containing the next key
NOD	INTEGER*4	number of the node containing the next key
PTR	INTEGER*4	number of the data record associated with the next key
KEYVAL	CHARACTER*20	value of the next key
ERR	BYTE	error code number

EXTERNALS:

none

SUBROUTINE FIRST

PURPOSE: To search for the first key in the tree.

INPUTS:

IO	BYTE	input/output device number
ROOT	INTEGER*4	node number of the tree root
HEIGHT	BYTE	height of the current tree

OUTPUTS:

MARK	INTEGER*4	position in the current node of the last key examined
MANY	INTEGER*4	number of keys in the current node
NOD	INTEGER*4	number of the current node
PTR	INTEGER*4	number of the data record associated with the last key examined
KEYVAL	CHARACTER*20	value of the last key examined
ERR	BYTE	error code number

EXTERNALS:

VAL

SUBROUTINE NEWROOT

PURPOSE: To create a new root.

INPUTS:

LFNOD	INTEGER*4	number of left node
RTNOD	INTEGER*4	number of right node
KEYVAL	CHARACTER*20	value of the first key in the right node
IO	BYTE	input/output device number
NAME	CHARACTER*9	name of the current tree
HTNOD	INTEGER*4	height of the node stack
MAXNOD	INTEGER*4	largest number yet assigned to a node

OUTPUTS:

ROOT	INTEGER*4	node number of the tree root
HEIGHT	BYTE	height of the current tree

EXTERNALS:

SYM,STACK

SUBROUTINE PARENT

PURPOSE: To update a parent node.

INPUTS:

LEVEL	BYTE	level of node last examined
LFNOD	INTEGER*4	number of left node
RTNOD	INTEGER*4	number of right node
BUF	CHARACTER*256	array which contains the nodes constituting the current path
ONE	INTEGER*4	parameter equal to MKL + 2
PATH	INTEGER*4	array which contains the node numbers defining the path from the root to the current node
INC	INTEGER*4	variable which determines the appropriate update action to be taken on the parent node
IO	BYTE	input/output device number
MKL	INTEGER*4	maximum key length
KEYVAL	CHARACTER*20	value of the separator key
PTR	INTEGER*4	number of the node to which the separator key points

OUTPUTS:

NOD	INTEGER*4	number of the parent node
MANY	INTEGER*4	updated number of keys in the parent node
BLOC	CHARACTER*256	updated parent node

EXTERNALS:

VAL,SYM

SUBROUTINE SPLIT

PURPOSE: To split a full node into two half-full nodes.

INPUTS:

IO	BYTE	input/output device number
NAME	CHARACTER*9	name of the current tree
HTNOD	INTEGER*4	height of the node stack
MAXNOD	INTEGER*4	largest number yet assigned to a node
FULL	INTEGER*4	maximum number of keys in a node
ONE	INTEGER*4	parameter equal to MKL + 2
BLOC	CHARACTER*256	current node
LEAF	LOGICAL	.TRUE. if and only if the current node is a leaf
NOD	INTEGER*4	number of the current node

OUTPUTS:

KEYVAL	CHARACTER*20	value of key in middle of current node
LFNOD	INTEGER*4	number of left node
RTNOD	INTEGER*4	number of right node

EXTERNALS:

SYM

SUBROUTINE ADDKEY

PURPOSE: To insert a key into the tree.

INPUTS:

ONE	INTEGER*4	parameter equal to MKL + 2
FULL	INTEGER*4	maximum number of keys in a node
IO	BYTE	input/output device number
NAME	CHARACTER*9	name of the current tree
HTREC	INTEGER*4	height of the record stack
MAXREC	INTEGER*4	largest number yet assigned to a data record

OUTPUTS:

ERR	BYTE	error code number

EXTERNALS:

GETKEY,STACK,SYM,PARENT,NEWROOT

SUBROUTINE LOOK

PURPOSE: To search a given node for the pointer to the next node in the path (if H < HEIGHT), or to search a leaf for the desired key (if H = HEIGHT).

INPUTS:

H	INTEGER*4	tree level of the current node
MANY	INTEGER*4	number of keys in the current node
ONE	INTEGER*4	parameter equal to MKL + 2
KEYVAL	CHARACTER*20	search string
BLOC	CHARACTER*256	current node
IO	BYTE	input/output device number
HEIGHT	BYTE	height of the current tree

OUTPUTS:

MARK	INTEGER*4	position in the current node of the last key examined
PTR	INTEGER*4	number of next node in path if H < HEIGHT; number of the data record associated with the last key examined if H = HEIGHT

EXTERNALS:

none

EXTERNALS:

LOOK

SUBROUTINE GETKEY

PURPOSE: To search for the first occurrence of the key having its first MATCH characters equal to the value of KEYVAL.

INPUTS:

ABC	CHARACTER*1	command letter
KEYVAL	CHARACTER*20	search string
IO	BYTE	input/output device number
MKL	INTEGER*4	maximum key length
ROOT	INTEGER*4	node number of the tree root
HEIGHT	BYTE	height of the current tree

OUTPUTS:

MATCH	INTEGER*4	number of characters in the search string
PTR	INTEGER*4	number of the data record associated with the last key examined
NOD	INTEGER*4	number of the current node
PATH	INTEGER*4	array which contains the node numbers defining the path from the root to the current node
BLOC	CHARACTER*256	current node
BUF	CHARACTER*256	array which contains the nodes in the current path
MANY	INTEGER*4	number of keys in the current node
MARK	INTEGER*4	position in the current node of the last key examined
KEYVAL	CHARACTER*20	value of last key examined
ERR	BYTE	error code number

SUBROUTINE OLDTREE

PURPOSE: To open an existing tree called NAME and initialize the associated parameters.

INPUTS:

IO	BYTE	input/output device number
NAME	CHARACTER*9	name of the current tree

OUTPUTS:

HTREC	INTEGER*4	height of the record stack
MAXREC	INTEGER*4	largest number yet assigned to a data record
HTNOD	INTEGER*4	height of the node stack
MAXNOD	INTEGER*4	largest number yet assigned to a node
ROOT	INTEGER*4	node number of the tree root
HEIGHT	BYTE	height of the current tree

EXTERNALS:

none

SUBROUTINE NEWTREE

PURPOSE: To create a tree called NAME and initialize the associated parameters.

INPUTS:

IO	BYTE	input/output device number
NAME	CHARACTER*9	name of the current tree

OUTPUTS:

HTREC	INTEGER*4	height of the record stack
MAXREC	INTEGER*4	largest number yet assigned to a data record
HTNOD	INTEGER*4	height of the node stack
MAXNOD	INTEGER*4	largest number yet assigned to a node
ROOT	INTEGER*4	node number of the tree root
HEIGHT	BYTE	height of the current tree

EXTERNALS:

none

SUBROUTINE SHARE

PURPOSE: To equally redistribute keys between adjacent right and left nodes.

INPUTS:

LEAF	LOGICAL	.TRUE. if and only if the current node is a leaf
LFM	INTEGER*4	number of keys in the left node
RTM	INTEGER*4	number of keys in the right node
LFBLOC	CHARACTER*256	left node
KEYVAL	CHARACTER*20	value of separator key
RTBLOC	CHARACTER*256	right node
RTNOD	INTEGER*4	number of the right node
LFNOD	INTEGER*4	number of the left node
ONE	INTEGER*4	parameter equal to MKL + 2

OUTPUTS:

KEYVAL	CHARACTER*20	value of updated separator key

EXTERNALS:

SYM

SUBROUTINE STACK

PURPOSE: To push or pop either the node stack or the record stack, as required.

INPUTS:

PTR	INTEGER*4	number pushed onto the stack, if ADD = 1
IO	BYTE	input/output device number
NAME	CHARACTER*9	name of the current tree
EXT	CHARACTER*3	file name extender which determines which stack, node or record, is to be updated
ADD	BYTE	push/pop stack indicator
HT	INTEGER*4	height of the stack
MOST	INTEGER*4	largest number yet assigned to a node or data record, depending on which stack is to be updated

OUTPUTS:

HT	INTEGER*4	height of the updated stack
MOST	INTEGER*4	largest number yet assigned to a node (if EXT = 'NOD') or data record (if EXT = 'REC')
PTR	INTEGER*4	number popped from stack, if ADD = -1

EXTERNALS:

SYM,VAL

FUNCTION VAL

PURPOSE: To convert a 2-BYTE symbol into an integer between 0 and 65,635.
(See FUNCTION SYM for the inverse function.)

INPUTS:

A	CHARACTER*2	2-BYTE symbol

OUTPUTS:

VAL	INTEGER*4	integer between 0 and 65,635 corresponding to A

EXTERNALS:

none

FUNCTION SYM

PURPOSE: To convert an integer beween 0 and 65,635 into a 2-BYTE symbol. (See FUNCTION VAL for the inverse function.)

INPUTS:

NUM	INTEGER*4	integer between 0 and 65,635

OUTPUTS:

SYM	CHARACTER*2	2-BYTE symbol corresponding to NUM

EXTERNALS:

none

PROGRAM DRIVER

PURPOSE: To directly examine a tree by means of an interactive diagnostic program; especially effective when used in conjunction with a debug utility program.

INPUTS:

none

OUTPUTS:

none

EXTERNALS:

none

APPENDIX B

FORTRAN CODE LISTING

```
      SUBROUTINE BTREE(LTR,LDU,A,MAXLEN,IREC,IERR)
C
C**********************************************************************
C        A 'B+ tree' is a data structure which is particularly well
C     suited for storing the keys which identify the data records
C     in a database.  Data is rapidly retrieved by minimizing the
C     number of mass storage accesses.  This implementation allows
C     a maximum of 65,535 keys, each having a maximum length of 20
C     characters; the tree has a maximum height of 5 and contains
C     256-byte nodes.  Numbers corresponding to deleted nodes or
C     records are placed in stacks and reused as needed.  Application
C     programs which call BTREE can have as many as 10 trees open
C     simultaneously.
C        For a basic introduction to the subject of B+ trees, see
C     "The Ubiquitous B Tree" by Douglas Comer, Computing Surveys,
C     11(1979)121-137; a more complete discussion can be found in
C     "The Art of Computer Programming, Vol.3: Sorting and Searching"
C     by Knuth, Addison-Wesley, 1973.
C        Complete documentation for BTREE is contained in
C     "BTREE : A FORTRAN Code for a B+ Tree" by Elliot Winston,
C     NSWC TR 85-54; a code for a database manager based on BTREE
C     is the subject of "BOSS : A FORTRAN Code for a Relational
C     Database Manager" by Elliot Winston, NSWC TR 85-56.
C**********************************************************************
C
C  INPUTS:
C
C       LTR (CHARACTER*1)      COMMAND ACTION
C
C             A        -       (A)DD A KEY TO THE TREE
C             C        -       (C)REATE A NEW TREE
C             D        -       (D)ELETE A KEY FROM THE TREE
C             F        -       GET THE (F)IRST KEY IN THE TREE
C             G        -       (G)ET FIRST OCCURRENCE OF A TRUNCATED KEY
C             O        -       (O)PEN AN OLD TREE
C             S        -       GET THE (S)UCCESSOR KEY
C
C       LDU (BYTE)             UNIT NUMBER UNDER WHICH THE TREE
C                              COMMUNICATES WITH MASS STORAGE
C
C       A (CHARACTER*20)       KEY VALUE (LTR = 'A','D','G');
C                              TREE NAME (LTR = 'C','O')
C
C       MAXLEN (INTEGER*4)     MAXIMUM KEY LENGTH (LTR = 'C')
C
C  OUTPUTS:
C
C       IREC (INTEGER*4)       NUMBER OF THE DATA RECORD ASSOCIATED
C                              WITH THE LAST KEY ACCESSED
C
C       A (CHARACTER*20)       VALUE OF LAST KEY ACCESSED
C
```

```
C       IERR (BYTE)             ERROR CODE
C
C             1         -       ILLEGAL VALUE OF PARAMETER 'LTR'
C             2         -       ATTEMPT TO CREATE EXISTENT TREE
C             3         -       ATTEMPT TO ACCESS NONEXISTENT TREE
C             4         -       ATTEMPT TO FIND NONEXISTENT KEY
C             5         -       NO SUCCESSOR EXISTS (LAST KEY IN TREE)
C             6         -       ATTEMPT TO INSERT KEY CURRENTLY IN TREE
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1   IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2   LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3   BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4   MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
          BYTE IO,ERR,LEVEL,HEIGHT
          CHARACTER ABC*1,NAME*9,KEYVAL*20
          CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
      BYTE IERR,LDU
      INTEGER MARKS(10),MANYS(10)
      CHARACTER LTR*1,A*20,BLOCS(10)*256
C
C-------------------------------------------------------------
C         CONTROL LOGICAL FLOW OF A COMMAND
C-------------------------------------------------------------
C
      IO = LDU
      ABC = LTR
      ERR = 0
      IF (ABC.NE.'C'.OR.ABC.NE.'O') THEN
         ONE = MKL(IO) + 2
         FULL = 252/ONE
      END IF
      IF (ABC.EQ.'A') THEN
         KEYVAL = A
         CALL ADDKEY
      ELSE IF (ABC.EQ.'C') THEN
         NAME(IO) = A
         MKL(IO) = MAXLEN
         CALL NEWTREE
      ELSE IF (ABC.EQ.'D') THEN
         KEYVAL = A
         CALL DELKEY
      ELSE IF (ABC.EQ.'F') THEN
         CALL FIRST
      ELSE IF (ABC.EQ.'G') THEN
         KEYVAL = A
         CALL GETKEY
      ELSE IF (ABC.EQ.'O') THEN
         NAME(IO) = A
```

```
      CALL OLDTREE
   ELSE IF (ABC.EQ.'S') THEN
      MARK = MARKS(IO)
      MANY = MANYS(IO)
      BLOC = BLOCS(IO)
      CALL SUCCESSOR
   ELSE
      ERR = 1
   END IF
   A = KEYVAL
   IREC = PTR
   IERR = ERR
   IF (ABC.EQ.'G'.OR.ABC.EQ.'F'.OR.ABC.EQ.'S') THEN
      MARKS(IO) = MARK
      MANYS(IO) = MANY
      BLOCS(IO) = BLOC
   END IF
   RETURN
   END
```

```
      SUBROUTINE NEWTREE
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1   IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2   LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3   BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4   MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
         BYTE IO,ERR,LEVEL,HEIGHT
         CHARACTER ABC*1,NAME*9,KEYVAL*20
         CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
      CHARACTER SYM*2,FN*13
      LOGICAL*1 THERE
C
  201 FORMAT(A256)
  202 FORMAT(7I5)
C
C-------------------------------------------------------------
C        CREATE A NEW TREE
C-------------------------------------------------------------
C
      CLOSE(UNIT=IO)
      FN = NAME(IO)//'.KEY'
      INQUIRE(FILE=FN,EXIST=THERE)
      IF (THERE) THEN
         ERR = 2
         RETURN
      END IF
      OPEN(UNIT=IO,FILE=FN,STATUS='NEW',FORM='FORMATTED',
     *     ACCESS='DIRECT',RECL=256)
      I = 0
      J = 0
      BLOC(1:2) = SYM(I)
      BLOC(3:4) = SYM(J)
      WRITE(IO,201,REC=2) BLOC
      J = 2
      BLOC(3:4) = SYM(J)
      WRITE(IO,201,REC=4) BLOC
      HTREC(IO) = 0
      MAXREC(IO) = 0
      HTNOD(IO) = 0
      MAXNOD(IO) = 2
      ROOT(IO) = 2
      HEIGHT(IO) = 0
C
C       ENTRY POINT FOR 'HEADER'
C
      ENTRY HEADER
      WRITE(IO,202,REC=1) HTREC(IO),MAXREC(IO),HTNOD(IO),MAXNOD(IO),
     *                    ROOT(IO),MKL(IO),HEIGHT(IO)
```

```
RETURN
END
```

```
      SUBROUTINE OLDTREE
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1   IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2   LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3   BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4   MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
         BYTE IO,ERR,LEVEL,HEIGHT
         CHARACTER ABC*1,NAME*9,KEYVAL*20
         CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
      CHARACTER*13 FN
      LOGICAL*1 THERE
C
  301 FORMAT(7I5)
C
C-----------------------------------------------------------------
C        OPEN AND  NITIALIZE AN OLD TREE
C-----------------------------------------------------------------
C
      FN = NAME(IO)//'.KEY'
      INQUIRE(FILE=FN,EXIST=THERE)
      IF (THERE) THEN
         CLOSE(UNIT=IO)
         OPEN(UNIT=IO,FILE=FN,STATUS='OLD',FORM='FORMATTED',
     *        ACCESS='DIRECT')
         READ(IO,301,REC=1) HTREC(IO),MAXREC(IO),HTNOD(IO),MAXNOD(IO),
     *                      ROOT(IO),MKL(IO),HEIGHT(IO)
      ELSE
         ERR = 3
         RETURN
      END IF
      RETURN
      END
```

```
      SUBROUTINE GETKEY
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1    IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2    LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3    BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4    MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
          BYTE IO,ERR,LEVEL,HEIGHT
          CHARACTER ABC*1,NAME*9,KEYVAL*20
          CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
  401 FORMAT(A256)
C
C-------------------------------------------------------------
C         SEARCH FOR FIRST OCCURRENCE OF A KEY HAVING
C         FIRST 'MATCH' CHARACTERS EQUAL TO 'KEYVAL'
C-------------------------------------------------------------
C
      IF (ABC.EQ.'G') THEN
         J = 20
         DO WHILE (KEYVAL(J:J).EQ.' ')
            J = J - 1
         END DO
         MATCH = J
      ELSE
         MATCH = MKL(IO)
      END IF
      PTR = ROOT(IO)
      HEND = HEIGHT(IO)
      DO 4015 H=0,HEND
         NOD = PTR
         PATH(H) = NOD
         READ(IO,401,REC=NOD) BLOC
         BUF(H) = BLOC
         MANY = VAL(BLOC(1:2))
         IF (MANY.EQ.0) THEN
C
C         EMPTY TREE
C
            MARK = 1
            ERR = 4
            RETURN
         ELSE
            CALL LOOK(H)
         END IF
 4015 CONTINUE
 4020 IF (MATCH.EQ.MKL(IO).OR.MARK.LT.MANY+1) GO TO 4030
C
C     EXTENDED SEARCH FOR A STRICTLY TRUNCATED KEY
C
```

```
      J = MANY*ONE + 3
      NOD = VAL(BLOC(J:J+1))
      IF (NOD.EQ.0) GO TO 4030
      PATH(HEND) = NOD
      READ(IO,401,REC=NOD) BLOC
      BUF(HEND) = BLOC
      MANY = VAL(BLOC(1:2))
      CALL LOOK(HEND)
      GO TO 4020
C
 4030 K = (MARK-1)*ONE + 3
      PTR = VAL(BLOC(K:K+1))
      IF (KEYVAL.EQ.BLOC(K+2:K+MATCH+1)) THEN
         ERR = 0
         KEYVAL = BLOC(K+2:K+MKL(IO)+1)
      ELSE
         ERR = 4
      END IF
      RETURN
      END
```

```
      SUBROUTINE SHARE(LEAF)
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1    IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2    LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3    BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4    MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
          BYTE IO,ERR,LEVEL,HEIGHT
          CHARACTER ABC*1,NAME*9,KEYVAL*20
          CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
      CHARACTER*2 SYM
      LOGICAL*1 LEAF
C
  201 FORMAT(A256)
C
C-------------------------------------------------------------
C         BALANCE ADJACENT NODES
C-------------------------------------------------------------
C
      MANY = (LFM + RTM)/2
      IF (MANY.EQ.LFM) THEN
         WRITE(IO,201,REC=NOD) BLOC
         RETURN
      END IF
      BLOC(1:2) = SYM(MANY)
      IF (MANY.LT.LFM) THEN
         I = 2 + MANY*ONE
         IF (LEAF) THEN
            BLOC(3:I) = LFBLOC(3:I)
            BLOC(I+1:I+2) = SYM(RTNOD)
            WRITE(IO,201,REC=LFNOD) BLOC
            J = 2 + LFM*ONE
            BLOC(3:J-I+2) = LFBLOC(I+1:J)
         ELSE
            BLOC(3:I+2) = LFBLOC(3:I+2)
            WRITE(IO,201,REC=LFNOD) BLOC
            J = 4 + LFM*ONE
            K = 4 + (LFM - MANY - 1)*ONE
            BLOC(3:K) = LFBLOC(I+ONE+1:J)
            BLOC(K+1:K+MKL(IO)) = KEYVAL
         END IF
         K = 3 + (LFM - MANY)*ONE
         MANY = LFM + RTM - MANY
         BLOC(K:4+MANY*ONE) = RTBLOC(3:4+RTM*ONE)
         KEYVAL = LFBLOC(I+3:I+ONE)
      ELSE
         I = 2 + LFM*ONE
         IF (LEAF) THEN
            BLOC(3:I) = LFBLOC(3:I)
```

```
      SUBROUTINE MERGE(LEAF)
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1   IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2   LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3   BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4   MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
         BYTE IO,ERR,LEVEL,HEIGHT
         CHARACTER ABC*1,NAME*9,KEYVAL*20
         CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
      BYTE ADD
      CHARACTER SYM*2,EXT*3
      LOGICAL*1 LEAF
C
  201 FORMAT(A256)
C
C-------------------------------------------------------------
C        MERGE ADJACENT NODES INTO THE LEFT NODE
C-------------------------------------------------------------
C
      IF (LEAF) THEN
         MANY = LFM + RTM
         BLOC(1:2) = SYM(MANY)
         BLOC(3:2+LFM*ONE) = LFBLOC(3:2+LFM*ONE)
         I = 3 + LFM*ONE
      ELSE
         MANY = LFM + RTM + 1
         BLOC(1:2) = SYM(MANY)
         BLOC(3:4+LFM*ONE) = LFBLOC(3:4+LFM*ONE)
         I = 5 + LFM*ONE
         BLOC(I:I+MKL(IO)-1) = KEYVAL
         I = I + MKL(IO)
      END IF
      BLOC(I:I+1+RTM*ONE) = RTBLOC(3:4+RTM*ONE)
      WRITE(IO,201,REC=LFNOD) BLOC
      ADD = 1
      EXT = 'NOD'
      CALL STACK(RTNOD,IO,NAME(IO),EXT,ADD,HTNOD(IO),MAXNOD(IO))
      RETURN
      END
```

```
      SUBROUTINE ADJACENT
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1   IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2   LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3   BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4   MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
         BYTE IO,ERR,LEVEL,HEIGHT
         CHARACTER ABC*1,NAME*9,KEYVAL*20
         CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
  501 FORMAT(A256)
C
C-------------------------------------------------------------
C        FIND ADJACENT NODES
C-------------------------------------------------------------
C
      MUCH = VAL(BUF(LEVEL-1)(1:2))
      DO 5005 M=1,MUCH
         I = 3 + (M-1)*ONE
         IF (VAL(BUF(LEVEL-1)(I:I+1)).EQ.NOD) GO TO 5010
 5005 CONTINUE
      MARK = MUCH
      I = 3 + (MARK-1)*ONE
      RTNOD = NOD
      RTBLOC = BLOC
      RTM = MANY
      LFNOD = VAL(BUF(LEVEL-1)(I:I+1))
      READ(IO,501,REC=LFNOD) LFBLOC
      LFM = VAL(LFBLOC(1:2))
      GO TO 5015
 5010 MARK = M
      I = 3 + (MARK-1)*ONE
      LFNOD = NOD
      LFBLOC = BLOC
      LFM = MANY
      RTNOD = VAL(BUF(LEVEL-1)(I+ONE:I+1+ONE))
      READ(IO,501,REC=RTNOD) RTBLOC
      RTM = VAL(RTBLOC(1:2))
 5015 KEYVAL = BUF(LEVEL-1)(I+2:I+1+MKL(IO))
      RETURN
      END
```

```
            IF (MANY.EQ.0) THEN
               ROOT(IO) = PATH(1)
               HEIGHT(IO) = HEIGHT(IO) - 1
               WRITE(IO,802,REC=1) HTREC(IO),MAXREC(IO),HTNOD(IO),
     *            MAXNOD(IO),ROOT(IO),MKL(IO),HEIGHT(IO)
            END IF
            WRITE(IO,801,REC=NOD) BLOC
            RETURN
         ELSE
            M = 2
            LEAF = .FALSE.
            GO TO 8005
         END IF
      ELSE
         CALL SHARE(LEAF)
         IF (MANY.EQ.LFM) RETURN
         INC = 0
         CALL PARENT(INC)
         WRITE(IO,801,REC=NOD) BLOC
         RETURN
      END IF
      END
```

```
      SUBROUTINE DELKEY
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1   IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2   LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3   BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4   MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
         BYTE IO,ERR,LEVEL,HEIGHT
         CHARACTER ABC*1,NAME*9,KEYVAL*20
         CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
      BYTE ADD
      CHARACTER SYM*2,EXT*3
      LOGICAL*1 LEAF
C
  801 FORMAT(A256)
  802 FORMAT(7I5)
C
C-------------------------------------------------------------
C        DELETE A KEY FROM THE TREE
C-------------------------------------------------------------
C
C        DELETE A KEY FROM A LEAF
C
      CALL GETKEY
      IF (ERR.NE.0) RETURN
      ADD = 1
      EXT = 'REC'
      CALL STACK(PTR,IO,NAME(IO),EXT,ADD,HTREC(IO),MAXREC(IO))
      L = 3 + (MARK-1)*ONE
      R = 4 + MANY*ONE
      BLOC(L:R) = BLOC(L+ONE:R+ONE)
      MANY = MANY - 1
      BLOC(1:2) = SYM(MANY)
      IF (MANY.GE.FULL/2.OR.HEIGHT(IO).EQ.0) THEN
         WRITE(IO,801,REC=NOD) BLOC
         RETURN
      END IF
C
C        UPDATE TREE
C
      LEVEL = HEIGHT(IO)
      M = 1
      LEAF = .TRUE.
 8005 CALL ADJACENT
      IF (LFM+RTM.LE.FULL-M) THEN
         CALL MERGE(LEAF)
         INC = -1
         CALL PARENT(INC)
         IF (MANY.GE.FULL/2.OR.LEVEL.EQ.0) THEN
```

```
      SUBROUTINE SUCCESSOR
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1   IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2   LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3   BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4   MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
         BYTE IO,ERR,LEVEL,HEIGHT
         CHARACTER ABC*1,NAME*9,KEYVAL*20
         CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
  801 FORMAT(A256)
C
C-------------------------------------------------------------
C        GET THE NEXT KEY IN SEQUENCE FOLLOWING THE LAST
C        KEY ACCESSED UNDER THE SAME INPUT/OUTPUT NUMBER
C-------------------------------------------------------------
C
      IF (MARK.LT.MANY) THEN
         MARK = MARK + 1
         GO TO 8010
      ELSE
         I = 3 + MANY*ONE
         NOD = VAL(BLOC(I:I+1))
         IF (NOD.EQ.0) THEN
            ERR = 5
            RETURN
         ELSE
            READ(IO,801,REC=NOD) BLOC
            MANY = VAL(BLOC(1:2))
            MARK = 1
         END IF
      END IF
 8010 K = 3 + (MARK-1)*ONE
      PTR = VAL(BLOC(K:K+1))
      KEYVAL = BLOC(K+2:K+MKL(IO)+1)
      RETURN
      END
```

```
      SUBROUTINE FIRST
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1   IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2   LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3   BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4   MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
         BYTE IO,ERR,LEVEL,HEIGHT
         CHARACTER ABC*1,NAME*9,KEYVAL*20
         CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
  701 FORMAT(A256)
C
C-------------------------------------------------------------
C        SEARCH FOR THE FIRST KEY IN THE TREE
C-------------------------------------------------------------
C
      NOD = ROOT(IO)
      HEND = HEIGHT(IO)
      DO 7005 H=0,HEND
         READ(IO,701,REC=NOD) BLOC
         IF (H.EQ.HEND) GO TO 7010
         NOD = VAL(BLOC(3:4))
 7005 CONTINUE
 7010 MARK = 1
      MANY = VAL(BLOC(1:2))
C
C        EMPTY TREE
C
      IF (MANY.EQ.0) THEN
         ERR = 4
         RETURN
      END IF
      PTR = VAL(BLOC(3:4))
      KEYVAL = BLOC(5:4+MKL(IO))
      RETURN
      END
```

```
      SUBROUTINE NEWROOT
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1   IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2   LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3   BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4   MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
         BYTE IO,ERR,LEVEL,HEIGHT
         CHARACTER ABC*1,NAME*9,KEYVAL*20
         CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
      BYTE ADD
      CHARACTER SYM*2,EXT*3
C
  701 FORMAT(A256)
  702 FORMAT(7I5)
C
C-------------------------------------------------------------
C        CREATE A NEW ROOT
C-------------------------------------------------------------
C
      MANY = 1
      BLOC(1:2) = SYM(MANY)
      BLOC(3:4) = SYM(LFNOD)
      BLOC(5:2+ONE) = KEYVAL
      BLOC(3+ONE:4+ONE) = SYM(RTNOD)
      ADD = -1
      EXT = 'NOD'
      CALL STACK(PTR,IO,NAME(IO),EXT,ADD,HTNOD(IO),MAXNOD(IO))
      WRITE(IO,701,REC=PTR) BLOC
      ROOT(IO) = PTR
      HEIGHT(IO) = HEIGHT(IO) + 1
      WRITE(IO,702,REC=1) HTREC(IO),MAXREC(IO),HTNOD(IO),MAXNOD(IO),
     *                    ROOT(IO),MKL(IO),HEIGHT(IO)
      RETURN
      END
```

```
BLOC(1:2) = SYM(MANY)
RETURN
END
```

```
      SUBROUTINE PARENT(INC)
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1   IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2   LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3   BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4   MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
         BYTE IO,ERR,LEVEL,HEIGHT
         CHARACTER ABC*1,NAME*9,KEYVAL*20
         CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
      CHARACTER*2 SYM
C
C-----------------------------------------------------------
C        UPDATE A PARENT NODE
C-----------------------------------------------------------
C
      LEVEL = LEVEL - 1
      NOD = PATH(LEVEL)
      BLOC = BUF(LEVEL)
      MANY = VAL(BLOC(1:2))
      DO 6005 M=1,MANY
         I = 3 + (M-1)*ONE
         IF(VAL(BLOC(I:I+1)).EQ.LFNOD) GO TO 6010
 6005 CONTINUE
      M = MANY + 1
 6010 L = 5 + (M-1)*ONE
      R = 4 + MANY*ONE
      IF (INC.EQ.-1) THEN
C
C        DELETE SEPARATOR FROM PARENT NODE
C
         IF (M.LT.MANY) BLOC(L:R) = BLOC(L+ONE:R+ONE)
C
      ELSE IF (INC.EQ.0) THEN
C
C        UPDATE VALUE OF SEPARATOR IN PARENT NODE
C
         BLOC(L:L+MKL(IO)-1) = KEYVAL
C
      ELSE
C
C        INSERT SEPARATOR INTO PARENT NODE
C
         IF (M.LE.MANY) BLOC(L+ONE:R+ONE) = BLOC(L:R)
         BLOC(L:L+MKL(IO)-1) = KEYVAL
         BLOC(L+MKL(IO):L+ONE-1) = SYM(RTNOD)
C
      END IF
      MANY = MANY + INC
```

```
      SUBROUTINE SPLIT(LEAF)
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1   IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2   LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3   BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4   MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
         BYTE IO,ERR,LEVEL,HEIGHT
         CHARACTER ABC*1,NAME*9,KEYVAL*20
         CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
      BYTE ADD
      CHARACTER SYM*2,EXT*3
      LOGICAL*1 LEAF
C
  601 FORMAT(A256)
C
C-------------------------------------------------------------
C        SPLIT A FULL NODE INTO TWO HALF-FULL NODES
C-------------------------------------------------------------
C
      ADD = -1
      EXT = 'NOD'
      CALL STACK(PTR,IO,NAME(IO),EXT,ADD,HTNOD(IO),MAXNOD(IO))
      MANY = FULL/2
      LFNOD = NOD
      LFBLOC(1:2) = SYM(MANY)
      I = 2 + MANY*ONE
      KEYVAL = BLOC(I+3:I+ONE)
      IF (LEAF) THEN
         LFBLOC(3:I) = BLOC(3:I)
         LFBLOC(I+1:I+2) = SYM(PTR)
         WRITE(IO,601,REC=NOD) LFBLOC
         MANY = FULL - MANY
      ELSE
         LFBLOC(3:I+2) = BLOC(3:I+2)
         WRITE(IO,601,REC=NOD) LFBLOC
         I = I + ONE
         MANY = FULL - 1 - MANY
      END IF
      RTNOD = PTR
      RTBLOC(1:2) = SYM(MANY)
      RTBLOC(3:4+MANY*ONE) = BLOC(I+1:4+FULL*ONE)
      WRITE(IO,601,REC=PTR) RTBLOC
      RETURN
      END
```

```
IF (LEVEL.GT.0) THEN
   INC = 1
   CALL PARENT(INC)
   IF (MANY.LT.FULL) THEN
      WRITE(IO,401,REC=NOD) BLOC
      RETURN
   ELSE
      LEAF = .FALSE.
      GO TO 4005
   END IF
ELSE
   CALL NEWROOT
END IF
RETURN
END
```

```
      SUBROUTINE ADDKEY
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1   IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2   LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3   BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4   MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
         BYTE IO,ERR,LEVEL,HEIGHT
         CHARACTER ABC*1,NAME*9,KEYVAL*20
         CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
      BYTE ADD
      CHARACTER SYM*2,EXT*3
      LOGICAL*1 LEAF
C
  401 FORMAT(A256)
C
C-------------------------------------------------------------
C        INSERT A KEY INTO THE TREE
C-------------------------------------------------------------
C
C        INSERT A KEY INTO A LEAF
C
      CALL GETKEY
      IF (ERR.EQ.0) THEN
         ERR = 6
         RETURN
      ELSE
         ERR = 0
      END IF
      ADD = -1
      EXT= 'REC'
      CALL STACK(PTR,IO,NAME(IO),EXT,ADD,HTREC(IO),MAXREC(IO))
      L = 3 + (MARK-1)*ONE
      R = 4 + MANY*ONE
      BLOC(L+ONE:R+ONE) = BLOC(L:R)
      BLOC(L:L+1) = SYM(PTR)
      BLOC(L+2:L+ONE-1) = KEYVAL
      MANY = MANY + 1
      BLOC(1:2) = SYM(MANY)
      IF (MANY.LT.FULL) THEN
         WRITE(IO,401,REC=NOD)BLOC
         RETURN
      END IF
C
C        UPDATE TREE
C
      LEVEL = HEIGHT(IO)
      LEAF = .TRUE.
 4005 CALL SPLIT(LEAF)
```

```
      SUBROUTINE LOOK(H)
C
      IMPLICIT INTEGER*4 (A-Z)
C
      COMMON /XXXTREE/
     1   IO,ERR,MARK,MANY,PTR,NOD,LEVEL,MATCH,ONE,FULL,ABC,
     2   LFM,RTM,LFNOD,RTNOD,KEYVAL,BLOC,LFBLOC,RTBLOC,
     3   BUF(0:5),PATH(0:5),HTREC(10),MAXREC(10),HTNOD(10),
     4   MAXNOD(10),ROOT(10),MKL(10),HEIGHT(10),NAME(10)
         BYTE IO,ERR,LEVEL,HEIGHT
         CHARACTER ABC*1,NAME*9,KEYVAL*20
         CHARACTER*256 BUF,BLOC,LFBLOC,RTBLOC
C
      CHARACTER*20 TRY
C
C-------------------------------------------------------------
C        SEARCH A GIVEN NODE
C-------------------------------------------------------------
C
      DO 5015 M=1,MANY
         K = 5 + (M-1)*ONE
         TRY = BLOC(K:K+MKL(IO)-1)
         IF (TRY.GE.KEYVAL) GO TO 5020
 5015 CONTINUE
      MARK = MANY + 1
      GO TO 5025
 5020 IF (H.EQ.HEIGHT(IO)) THEN
         MARK = M
      ELSE
         IF (TRY.EQ.KEYVAL) THEN
            MARK = M + 1
         ELSE
            MARK = M
         END IF
      END IF
 5025 K = (MARK-1)*ONE + 3
      PTR = VAL(BLOC(K:K+1))
      RETURN
      END
```

```
            J = 2 + (MANY-LFM)*ONE
            BLOC(I+1:I+J-2) = RTBLOC(3:J)
            K = I + J - 1
            BLOC(K:K+1) = SYM(RTNOD)
        ELSE
            BLOC(3:I+2) = LFBLOC(3:I+2)
            BLOC(I+3:I+ONE) = KEYVAL
            J = 2 + (MANY-1-LFM)*ONE
            I = I + ONE
            BLOC(I+1:I+J) = RTBLOC(3:J+2)
        END IF
        WRITE(IO,201,REC=LFNOD) BLOC
        K = 3 + (MANY - LFM)*ONE
        MANY = LFM + RTM - MANY
        BLOC(3:4+MANY*ONE) = RTBLOC(K:4+RTM*ONE)
        KEYVAL = RTBLOC(J+3:J+ONE)
    END IF
    BLOC(1:2) = SYM(MANY)
    WRITE(IO,201,REC=RTNOD) BLOC
    RETURN
    END
```

```
      SUBROUTINE STACK(PTR,IO,NAME,EXT,ADD,HT,MOST)
C
      IMPLICIT INTEGER*4 (A-Z)
C
      CHARACTER SYM*2,EXT*3,NAME*9,FN*13,B*128
      BYTE ADD,IO
C
  901 FORMAT(A128)
C
C-------------------------------------------------------------
C        PUSH/POP (ACCORDING TO ADD = 1,-1) THE RECORD/NODE
C              STACK (ACCORDING TO EXT = 'REC','NOD')
C-------------------------------------------------------------
C
      IF (HT.GT.0.OR.ADD.EQ.1) THEN
         CLOSE(UNIT=IO)
         FN = NAME//'.'//EXT
         OPEN(UNIT=IO,FILE=FN,STATUS='UNKNOWN',FORM='FORMATTED',
     *        ACCESS='DIRECT',RECL=128)
         I = 1 + HT/64
         J = MOD(HT,64)
         K = 2*J
         HT = HT + ADD
         IF (ADD.EQ.1) THEN
            IF (K.GT.0) READ(IO,901,REC=I) B
            B(K+1:K+2) = SYM(PTR)
            WRITE(IO,901,REC=I) B
         ELSE
            IF (J.EQ.0) THEN
               I = I - 1
               K = 126
            ELSE
               K = K - 2
            END IF
            READ(IO,901,REC=I) B
            PTR = VAL(B(K+1:K+2))
         END IF
         IF (HT.EQ.0) THEN
            CLOSE(UNIT=IO,STATUS='DELETE')
         ELSE
            CLOSE(UNIT=IO)
         END IF
         FN = NAME//'.KEY'
         OPEN(UNIT=IO,FILE=FN,STATUS='OLD',FORM='FORMATTED',
     *        ACCESS='DIRECT')
       ELSE
         MOST = MOST + 1
         PTR = MOST
       END IF
C
C        ENTRY POINT OF 'HEADER' IS LOCATED IN 'NEWTREE'
C
```

```
      CALL HEADER
      RETURN
      END
```

```
      FUNCTION VAL(A)
C
      IMPLICIT INTEGER*4 (A-Z)
C
      CHARACTER*2 A
C
C-----------------------------------------------------------
C         CONVERT CODED 2-BYTE SYMBOL INTO AN
C             INTEGER BETWEEN 0 AND 65535
C-----------------------------------------------------------
C
      VAL = ICHAR(A(1:1))
      J = ICHAR(A(2:2))
      K = 2**8
      DO 1005 I=0,7
         VAL = VAL + IBITS(J,I,1)*K
         K = 2*K
 1005 CONTINUE
      RETURN
      END
```

```
      CHARACTER*2 FUNCTION SYM(NUM)
C
      IMPLICIT INTEGER*4 (A-Z)
C
C-----------------------------------------------------------------
C          CONVERT AN INTEGER BETWEEN 0 AND 65535
C                INTO A CODED 2-BYTE SYMBOL
C-----------------------------------------------------------------
C
      DO 2010 J=1,2
         SUM = 0
         K = 1
         DO 2005 I=0,7
            SUM = SUM + IBITS(NUM,(J-1)*8+I,1)*K
            K = 2*K
 2005    CONTINUE
         SYM(J:J) = CHAR(SUM)
 2010 CONTINUE
      RETURN
      END
```

```
      PROGRAM DRIVER
C
      CHARACTER LTR*1,A*20
C
   10 FORMAT(A1)
   11 FORMAT(A25)
   21 FORMAT(10X,' ILLEGAL VALUE OF LTR')
   22 FORMAT(10X,' TREE CURRENTLY EXISTS')
   23 FORMAT(10X,' NONEXISTENT TREE')
   24 FORMAT(10X,' CANNOT FIND DESIRED KEY VALUE')
   25 FORMAT(10X,' NO SUCCESSOR KEY EXISTS')
   26 FORMAT(10X,' KEY CURRENTLY EXISTS IN TREE')
C
C-------------------------------------------------------------
C        PROGRAM TO DIRECTLY EXAMINE A TREE
C-------------------------------------------------------------
C
      WRITE(6,*)' ENTER LOGICAL UNIT NUMBER'
      READ(5,*) LDU
  100 WRITE(6,*) ' '
      WRITE(6,*)' A - add       D - delete   G - get          key'
      WRITE(6,*)'       F - first        S - successor      key'
      WRITE(6,*)'       O - open         C - create         tree'
      WRITE(6,*)' ENTER LETTER'
      READ(5,10) LTR
      IF (LTR.EQ.'A'.OR.LTR.EQ.'D'.OR.LTR.EQ.'G') THEN
         WRITE(6,*)' ENTER KEY VALUE'
         READ(5,11) A
      ELSE IF (LTR.EQ.'O'.OR.LTR.EQ.'C') THEN
         WRITE(6,*)' ENTER TREE NAME'
         READ(5,11) A
         IF (LTR.EQ.'C') THEN
            WRITE(6,*)' ENTER LENGTH OF PRIMARY KEY'
            READ(5,*) MAXLEN
         END IF
      END IF
      CALL BTREE(LTR,LDU,A,MAXLEN,IREC,IERR)
C
      IF (IERR.EQ.0) THEN
         GO TO 200
      ELSE IF (IERR.EQ.1) THEN        ! ILLEGAL VALUE OF 'LTR'
         WRITE(6,21)
      ELSE IF (IERR.EQ.2) THEN        ! TREE CURRENTLY EXISTS
         WRITE(6,22)
      ELSE IF (IERR.EQ.3) THEN        ! NONEXISTENT TREE
         WRITE(6,23)
      ELSE IF (IERR.EQ.4) THEN        ! CANNOT FIND KEY
         WRITE(6,24)
      ELSE IF (IERR.EQ.5) THEN        ! NO SUCCESSOR KEY
         WRITE(6,25)
      ELSE IF (IERR.EQ.6) THEN        ! KEY CURRENTLY EXISTS
         WRITE(6,26)
```

```
      END IF
      WRITE(6,*)' '
      WRITE(6,*)'          REQUEST VOIDED'
      WRITE(6,*)' '
C
  200 WRITE(6,*)' DO YOU WISH TO EXIT?  (Y/N)'
      READ (5,10) LTR
      IF(LTR.EQ.'N') GO TO 100
      STOP
      END
```

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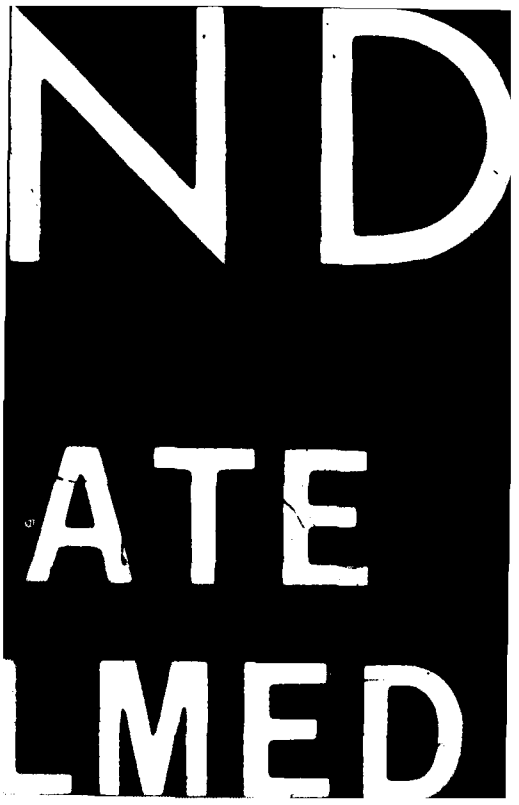
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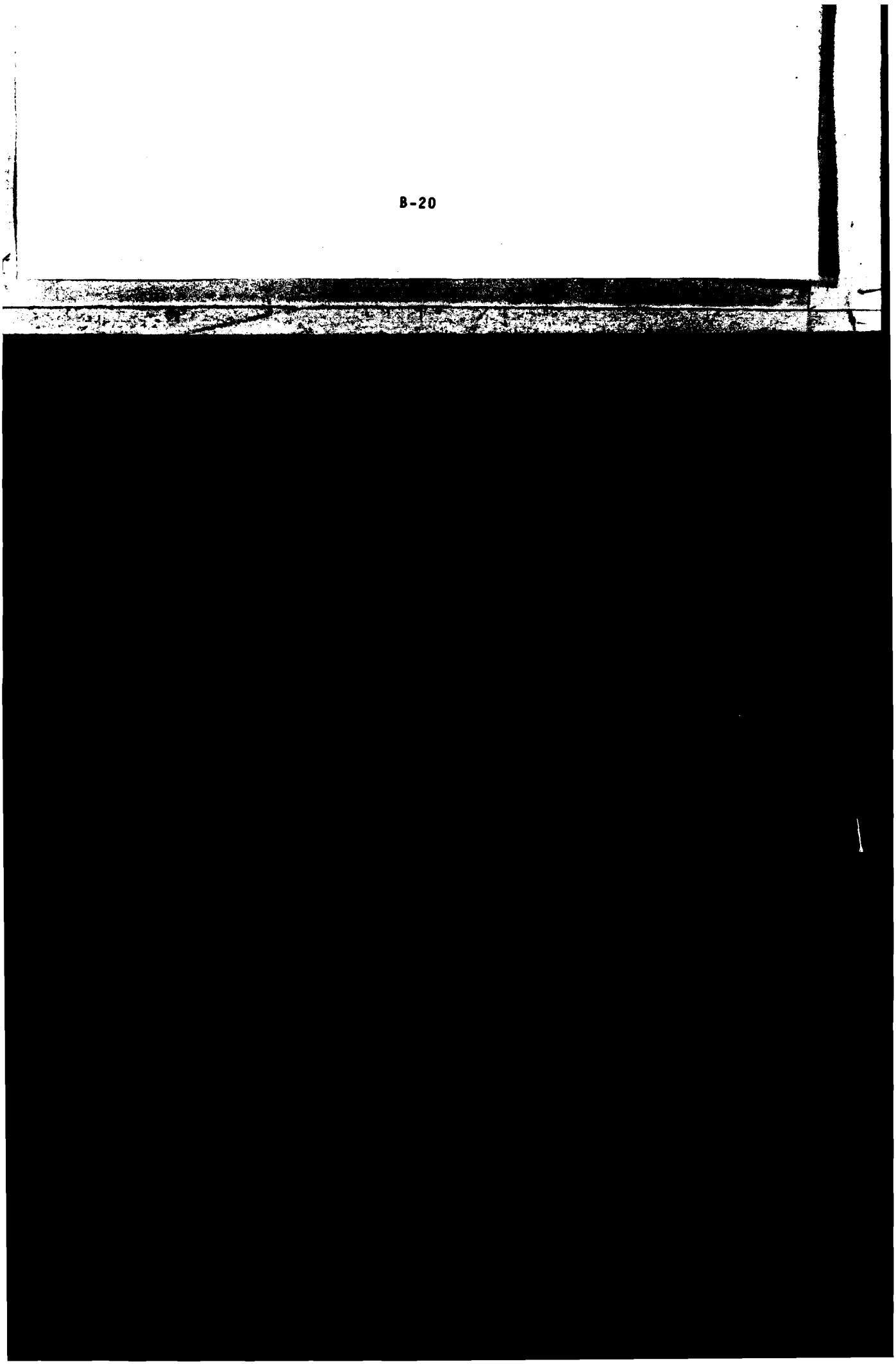
```
C
      LEVEL = HEIGHT(IO)
      M = 1
      LEAF = .TRUE.
 8005 CALL ADJACENT
      IF (LFM+RTM.LE.FULL-M) THEN
         CALL MERGE(LEAF)
         INC = -1
         CALL PARENT(INC)
         IF (MANY.GE.FULL/2.OR.LEVEL.EQ.0) THEN
```



```
      RETURN
      END
```

END

```
      BLOC(3:K) = LFBLOC(I+ONE+1:J)
      BLOC(K+1:K+MKL(IO)) = KEYVAL
   END IF
   K = 3 + (LFM - MANY)*ONE
   MANY = LFM + RTM - MANY
   BLOC(K:4+MANY*ONE) = RTBLOC(3:4+RTM*ONE)
   KEYVAL = LFBLOC(I+3:I+ONE)
ELSE
   I = 2 + LFM*ONE
   IF (LEAF) THEN
      BLOC(3:I) = LFBLOC(3:I)
```

```
     *         ACCESS='DIRECT')
          ELSE
             MOST = MOST + 1
             PTR = MOST
          END IF
C
C            ENTRY POINT OF 'HEADER' IS LOCATED IN 'NEWTREE'
C
```

[redacted]

```
    WRITE(6,22)
ELSE IF (IERR.EQ.3) THEN          ! NONEXISTENT TREE
    WRITE(6,23)
ELSE IF (IERR.EQ.4) THEN          ! CANNOT FIND KEY
    WRITE(6,24)
ELSE IF (IERR.EQ.5) THEN          ! NO SUCCESSOR KEY
    WRITE(6,25)
ELSE IF (IERR.EQ.6) THEN          ! KEY CURRENTLY EXISTS
    WRITE(6,26)
```